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(54) SHAPE MEMORY ALLOY-ACTUATED AND BENDER-ACTUATED HELICAL SPRING BRAKES

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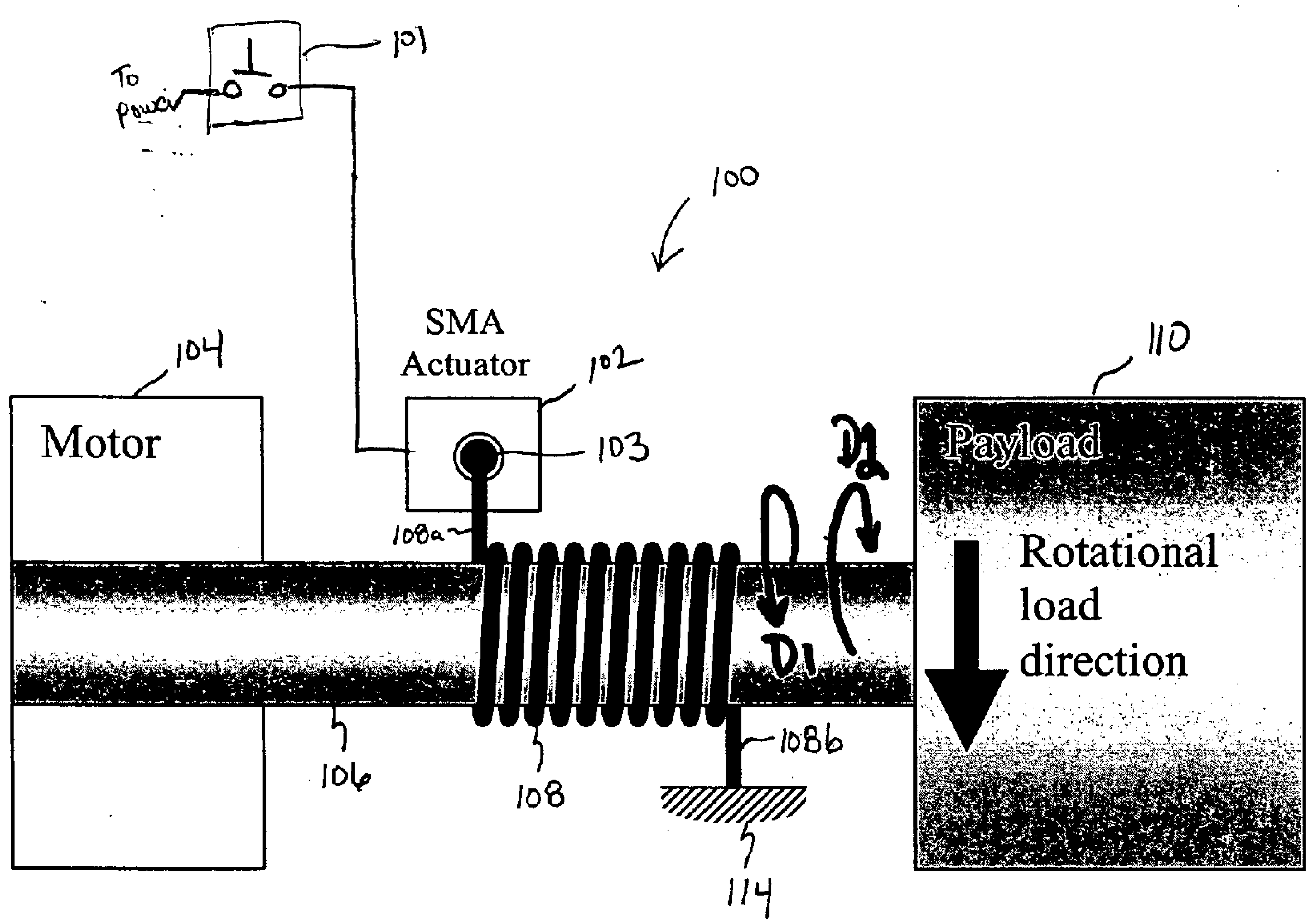
(57) ABSTRACT

In one embodiment of the present invention, a shape memory alloy ("SMA")-actuated helical spring brake comprises a rotatable member and a helical wrap spring arranged concentrically about the rotatable member. The spring has a first spring end and a second spring end and includes a number of turns that are based radially inward and are configured to frictionally engage the rotatable member. The turns permit rotation of the rotatable member in a first direction and inhabit rotation in a second direction. The SMA-actuate helical spring brake also include an anchor point coupled to the second spring end, and an SMA actuator having an output drive member coupled to the first spring end. The SMA actuator is configured to, for example, deflect the first spring end to permit the rotatable member to rotate.



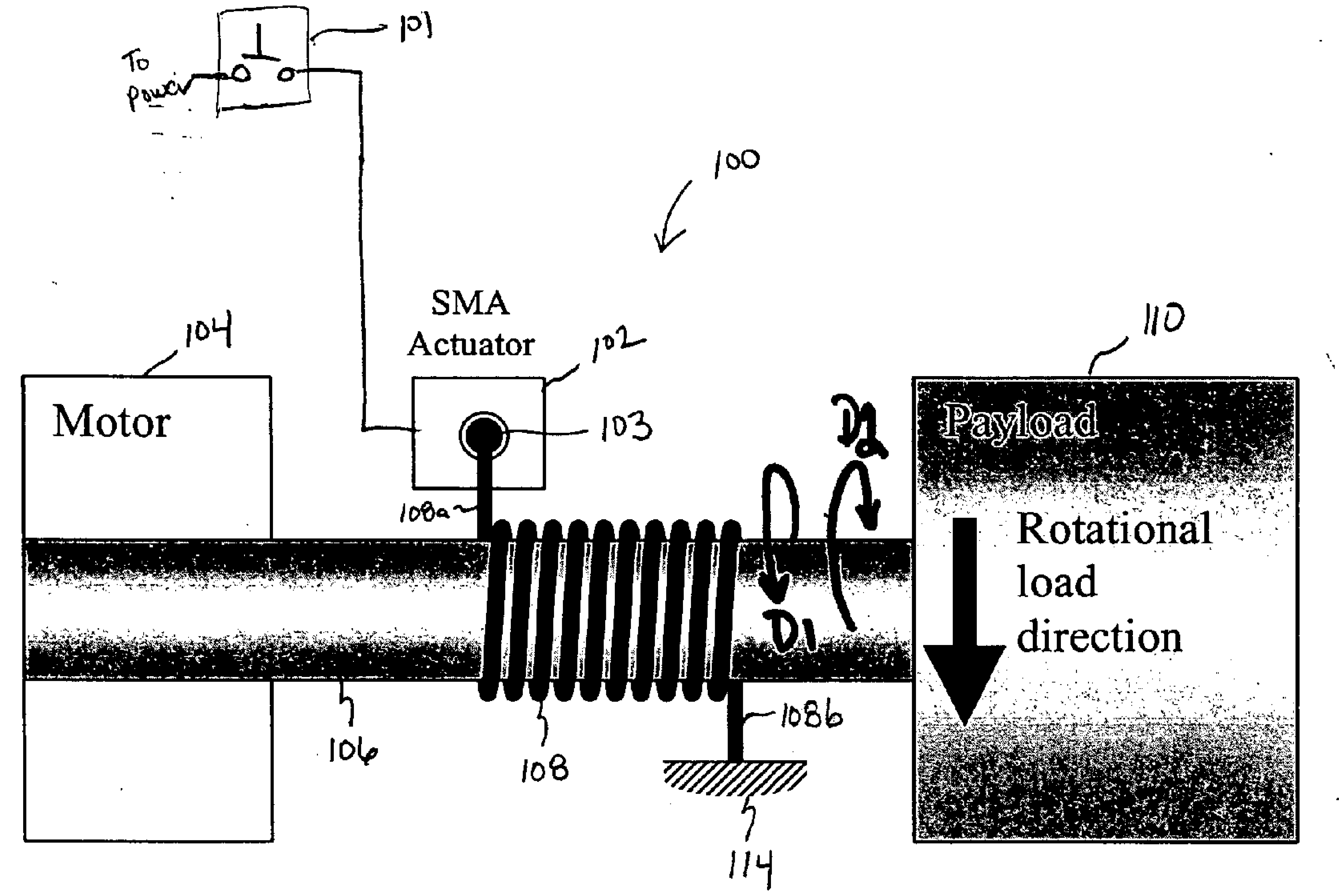

101
To power
100
SMA Actuator
102
104
Motor
103
108a
D2
D1
110
Payload
Rotational load direction
106
108
108b
114

FIG. 1

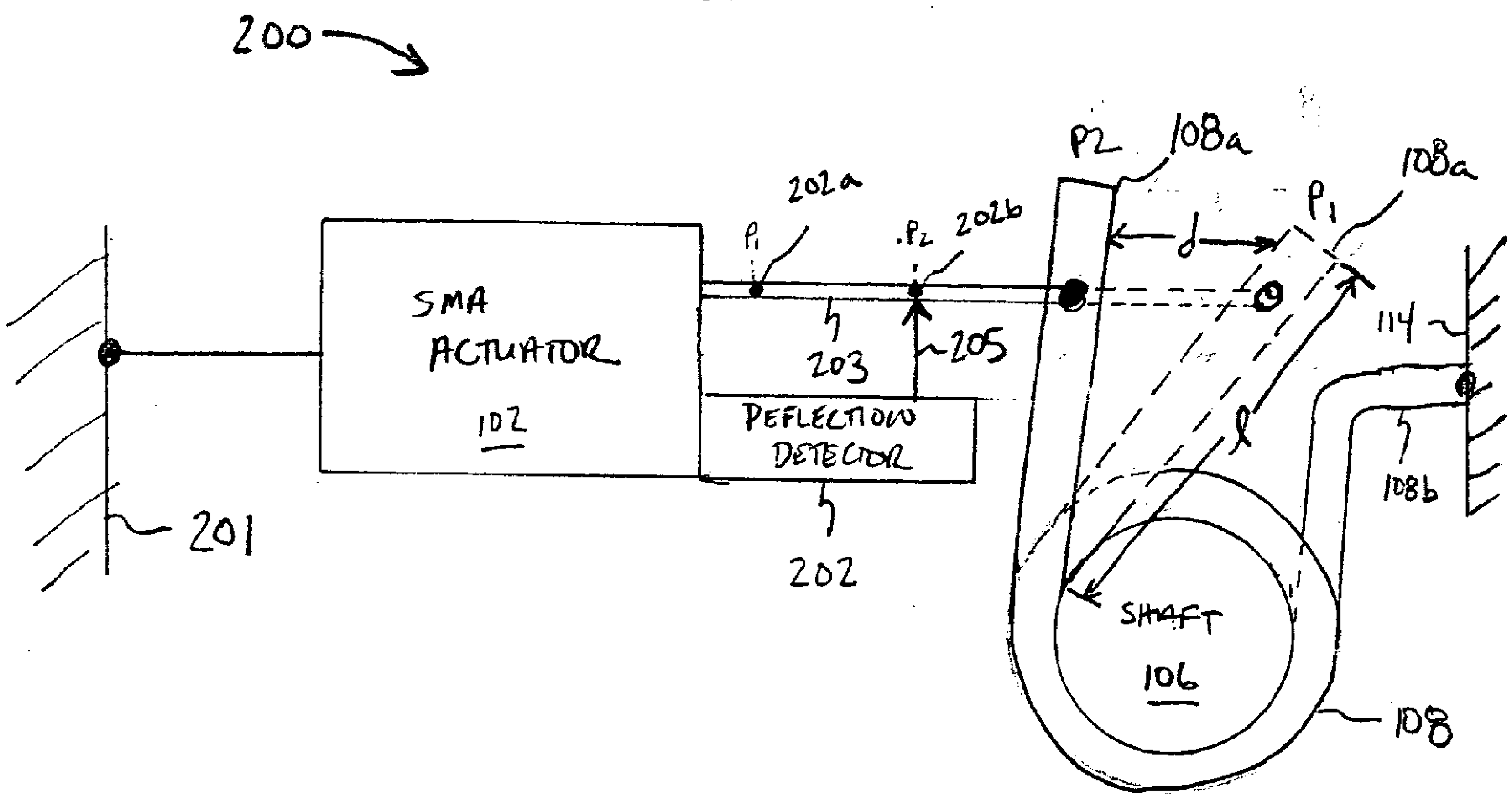

200
P2
108a
108a
202a
P1
P2
202b
d
P1
SMA ACTUATOR
102
203
205
114
DEFLECTION DETECTOR
l
108b
201
202
SHAFT
106
108

FIG. 2A

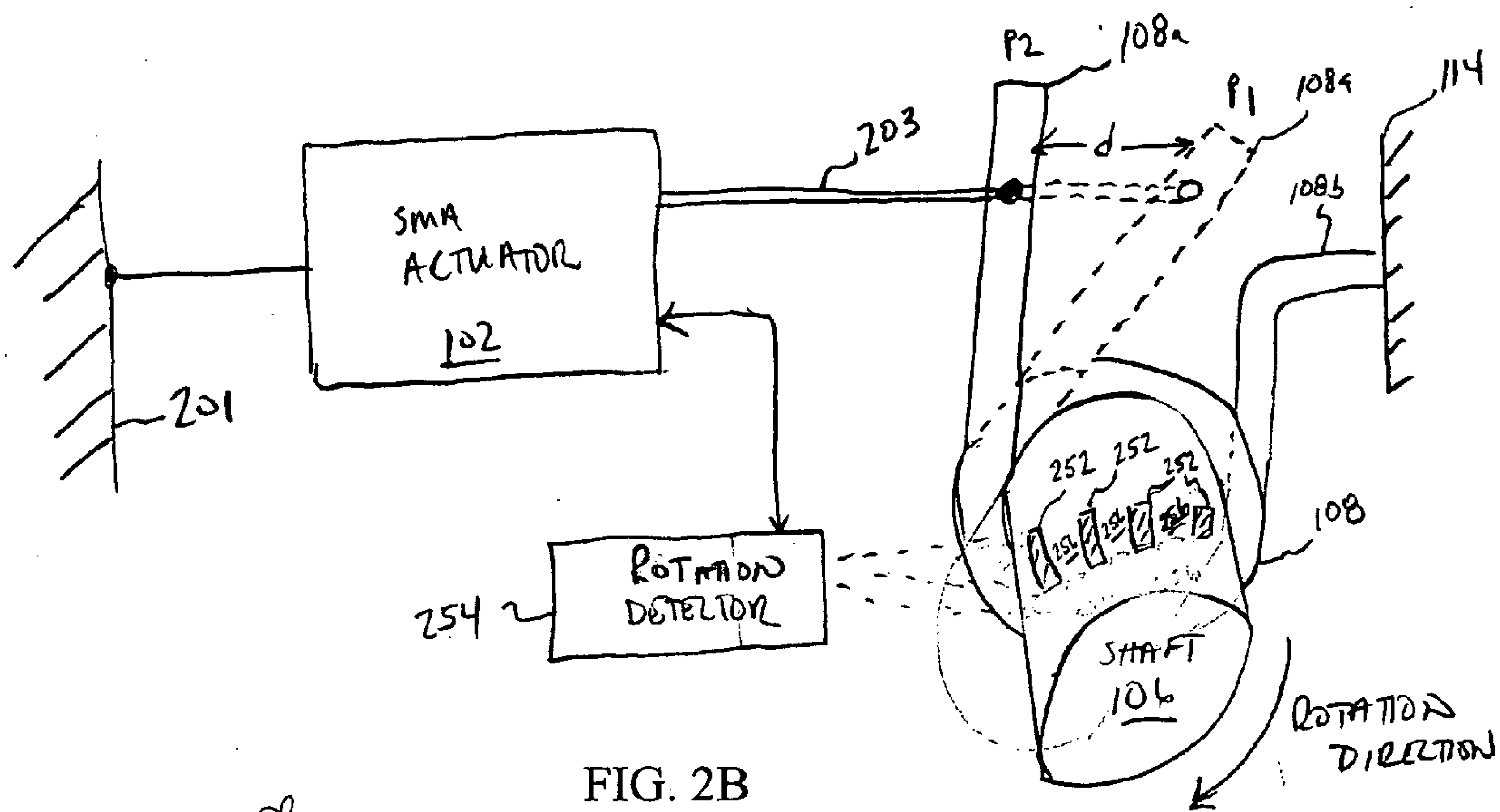

P2
108a
P1
108a
114
203
d
108b
SMA
ACTUATOR
102
201
252
252
252
108
ROTATION
DETECTOR
254
SHAFT
106
ROTATION
DIRECTION

FIG. 2B

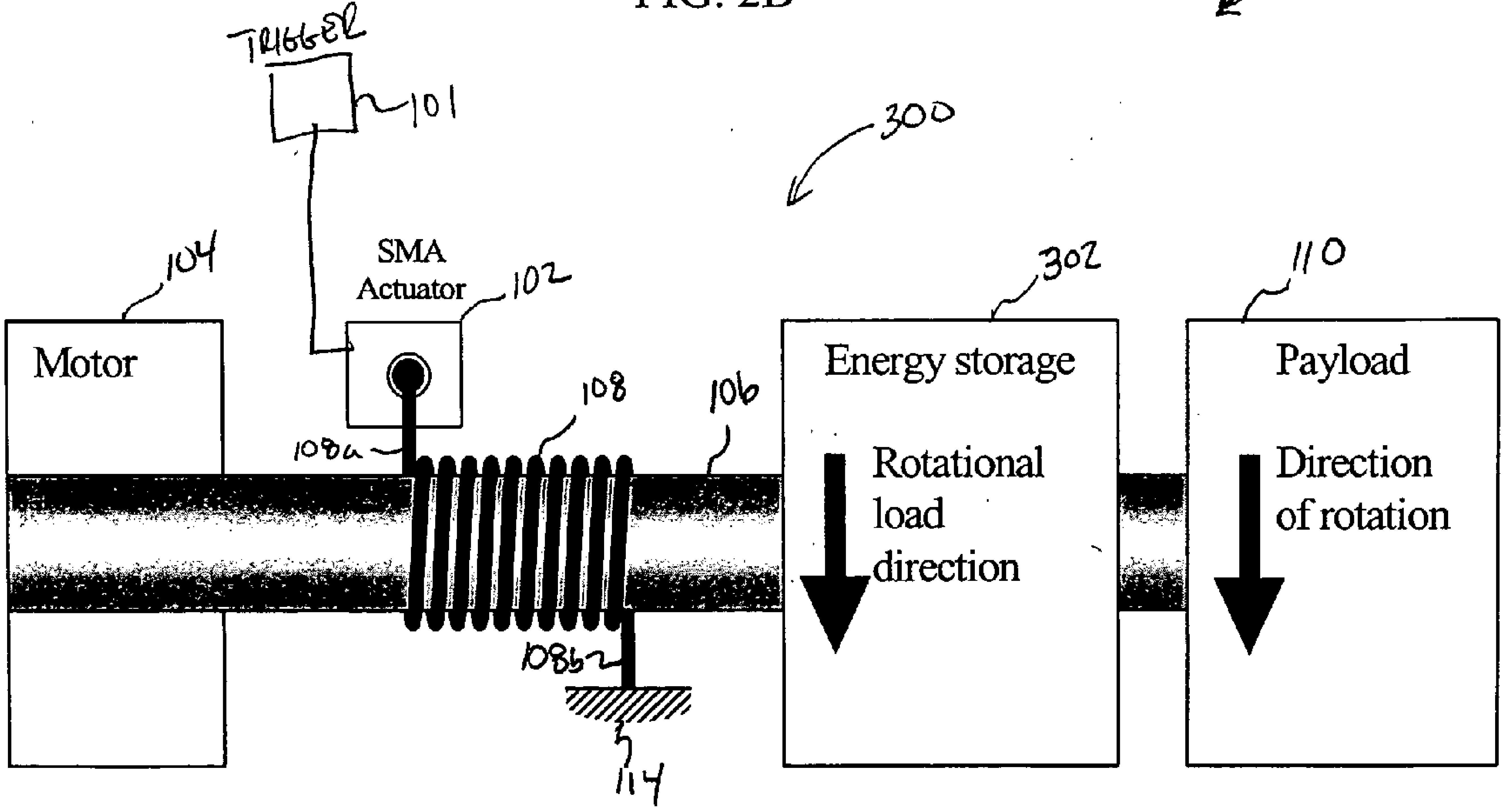

TRIGGER
101
300
104
SMA
Actuator
102
302
110
Motor
Energy storage
Payload
108
106
108a
Rotational
load
direction
Direction
of rotation
108b
114

FIG. 3

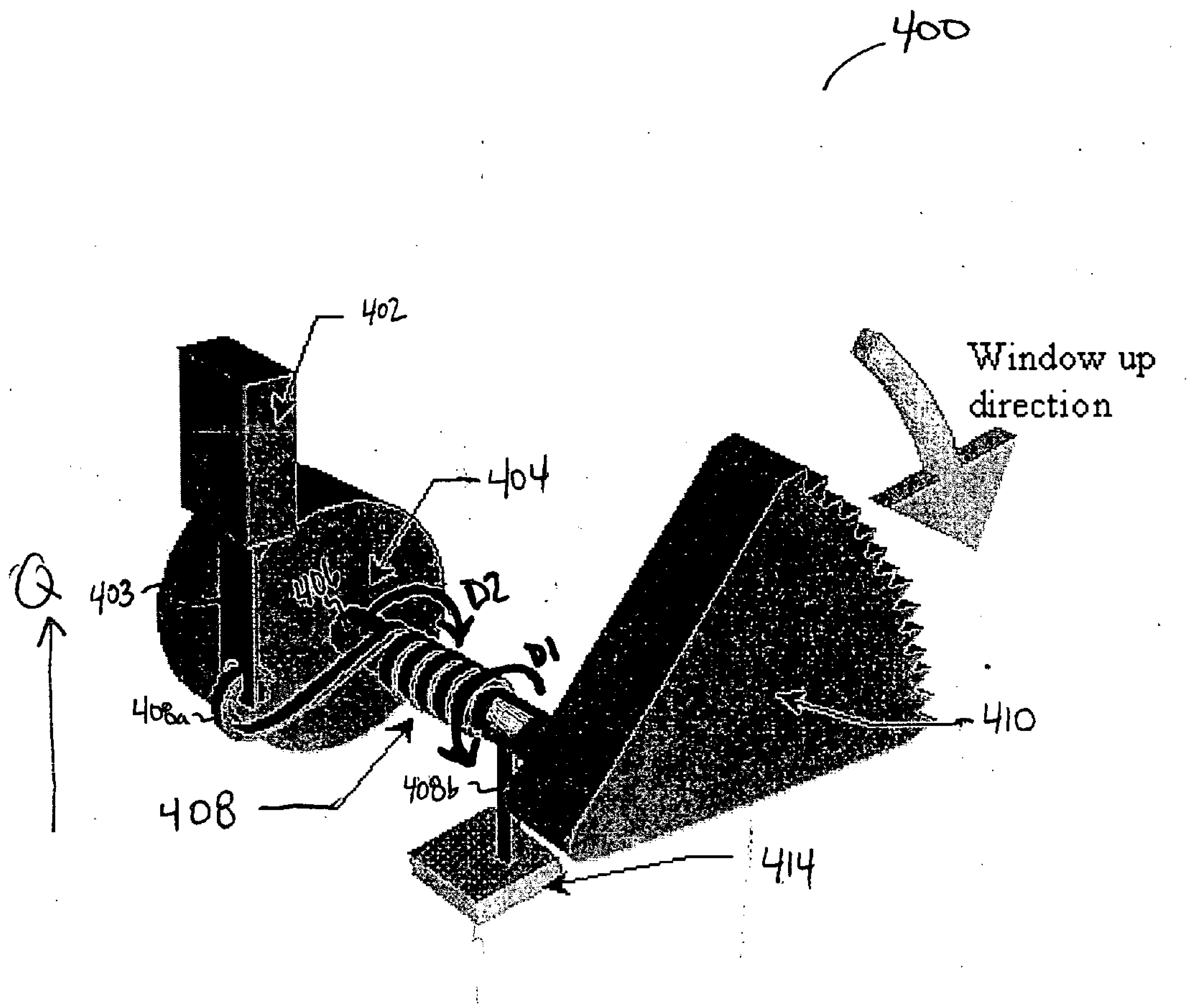

400
402
Window up
direction
404
Q
403
406
D2
D1
408a
410
408
408b
414

FIG. 4

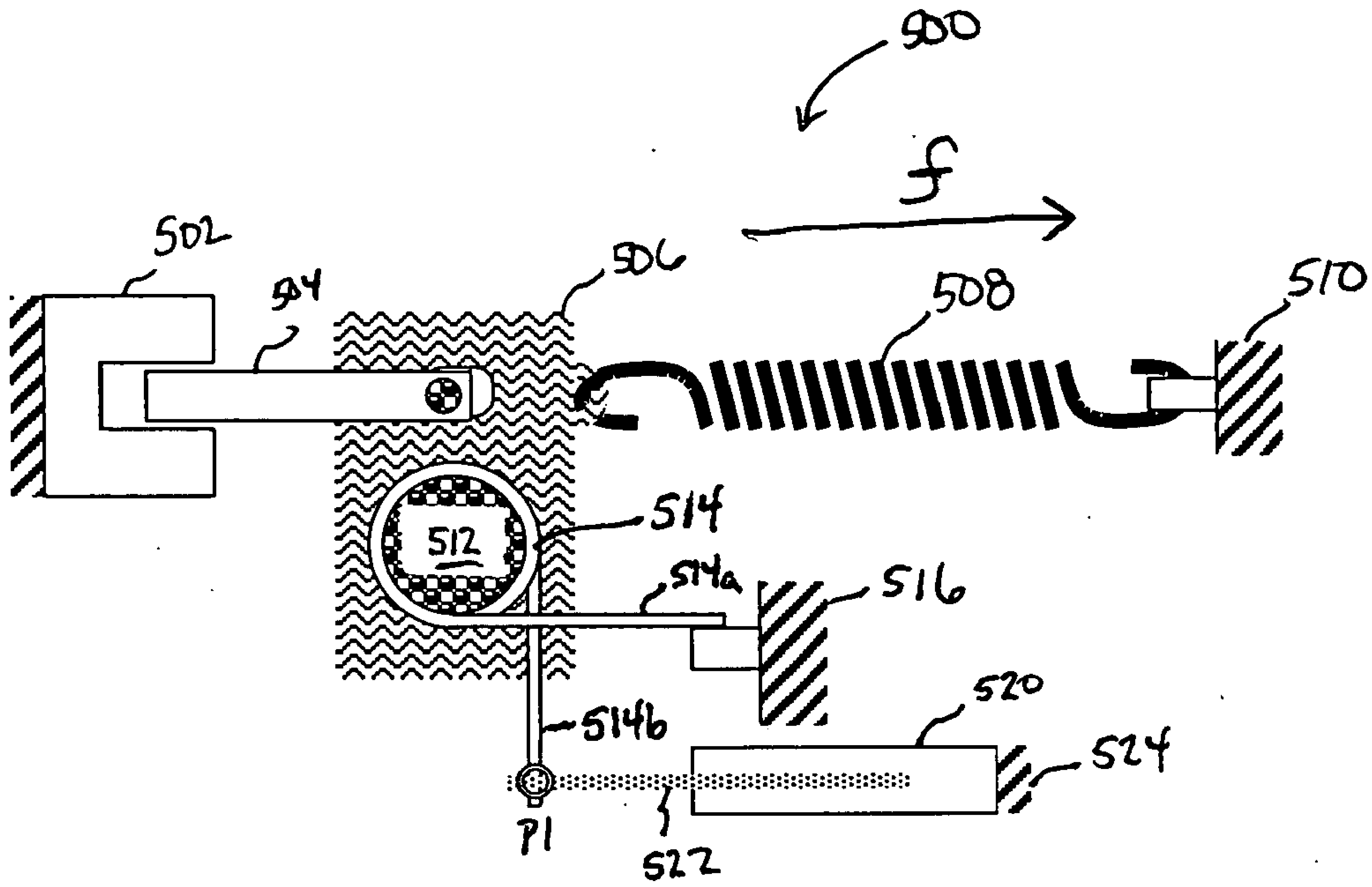

500
f
502
504
506
508
510
514
512
514a
516
520
514b
524
P1
522

FIG. 5

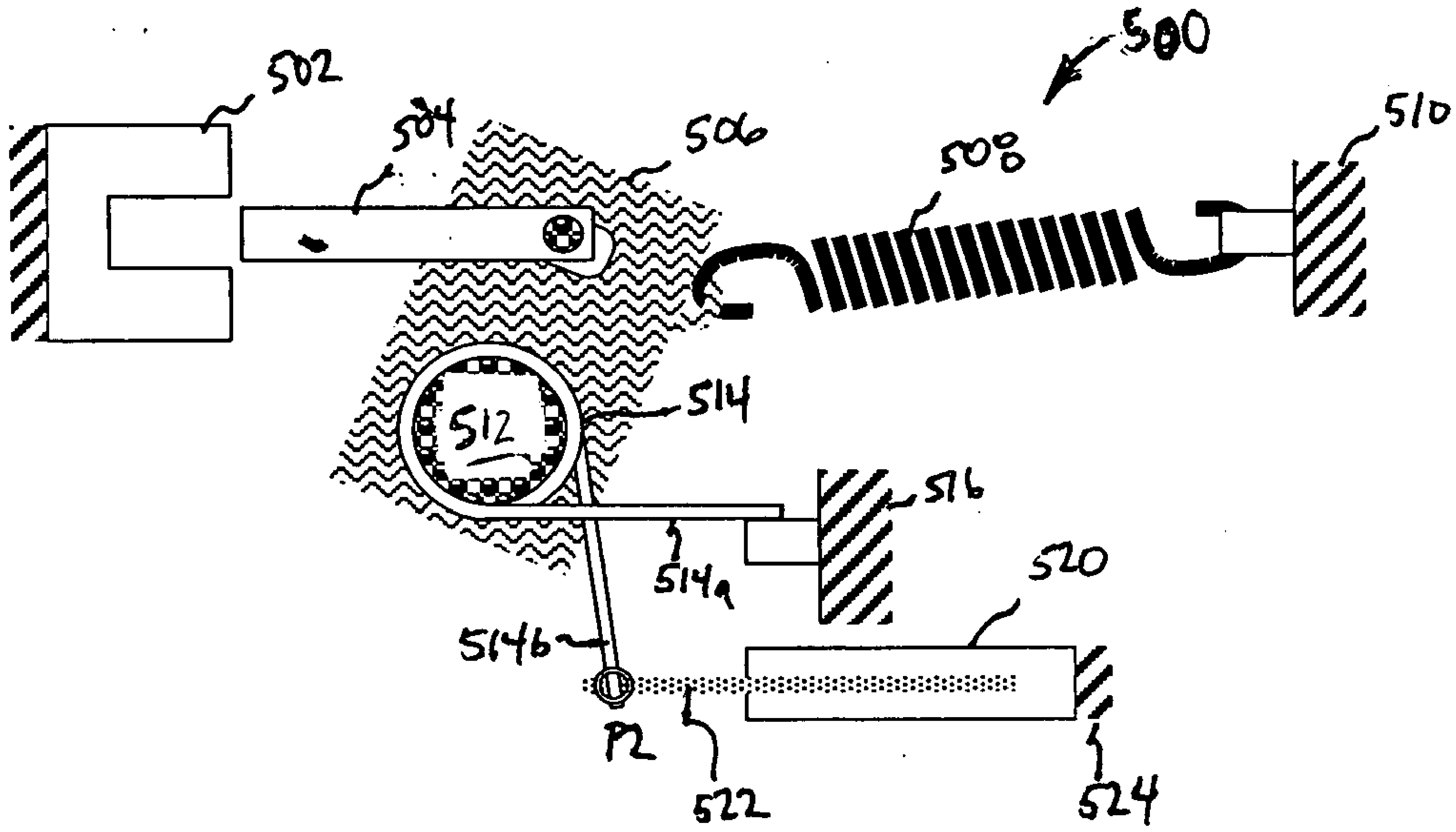

500
502
504
506
508
510
512
514
516
514a
520
514b
P2
522
524

FIG. 6

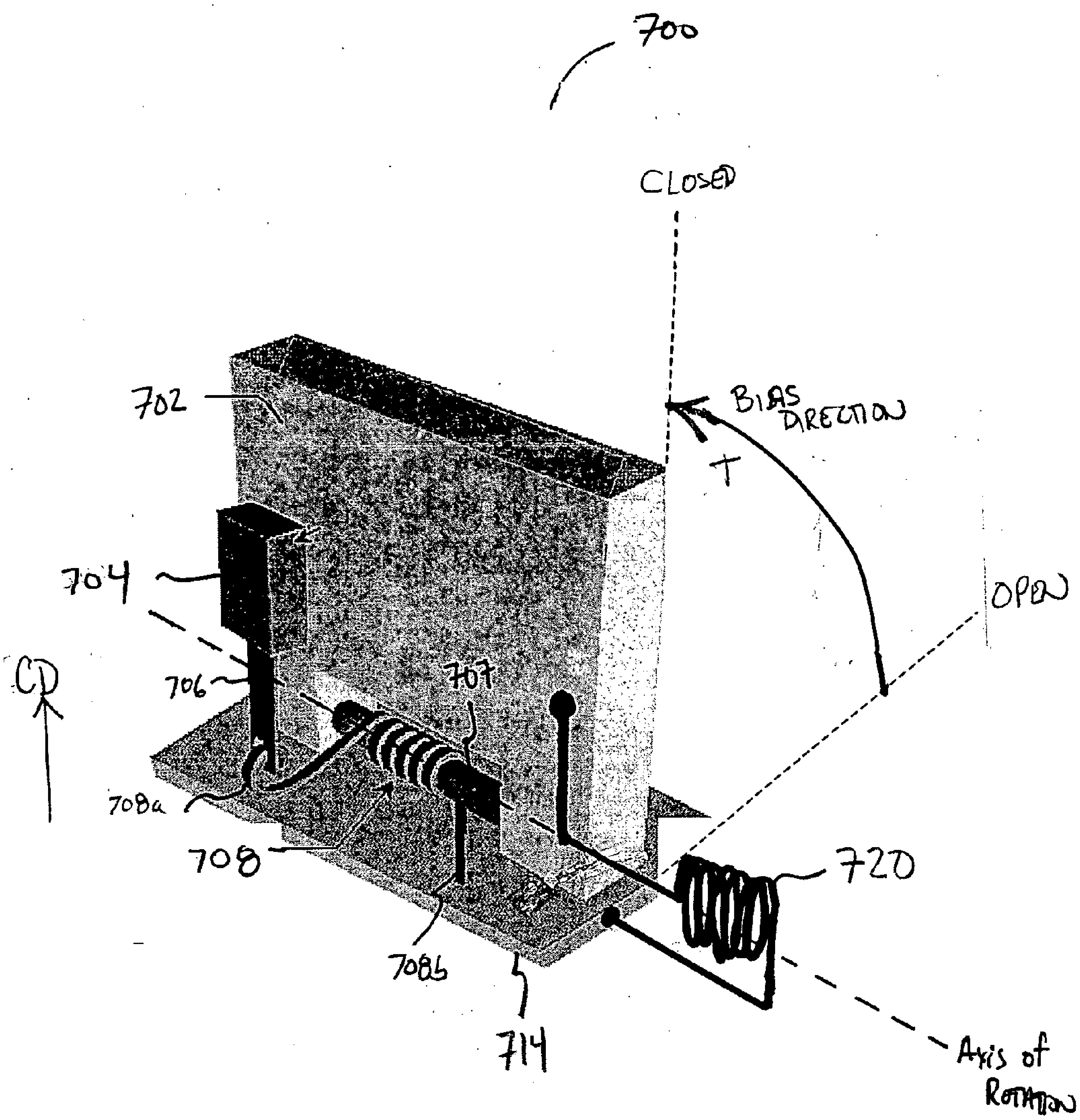

700
CLOSED
702
BIAS DIRECTION
T
704
OPEN
CD
706
707
708a
708
720
708b
714
Axis of Rotation

FIG. 7

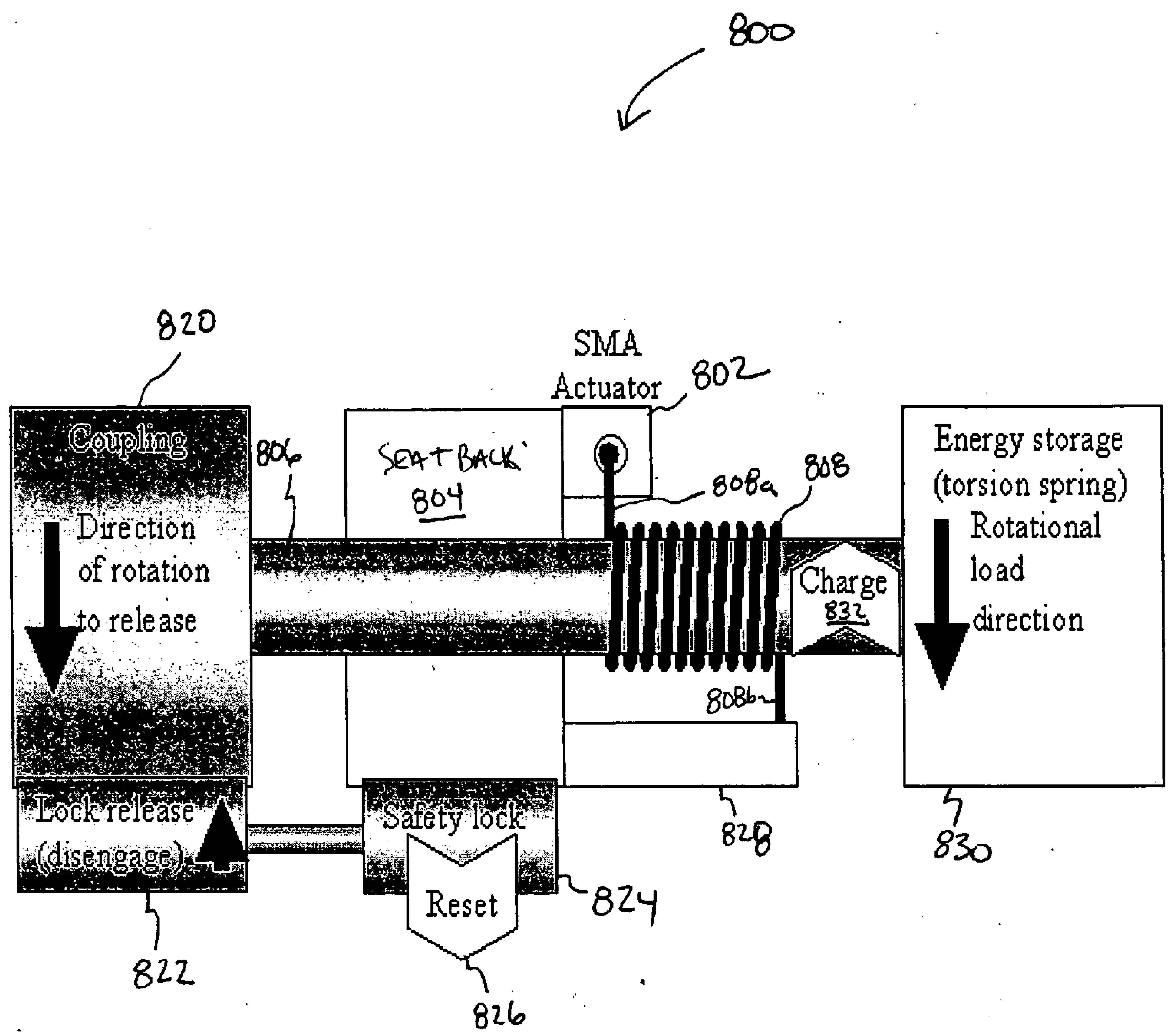

800
820
Coupling
Direction of rotation to release
806
SMA Actuator
802
SEAT BACK 804
808a
808
Energy storage (torsion spring)
Rotational load direction
Charge 832
808b
Lock release (disengage)
Safety lock
Reset
824
828
830
822
826

FIG. 8

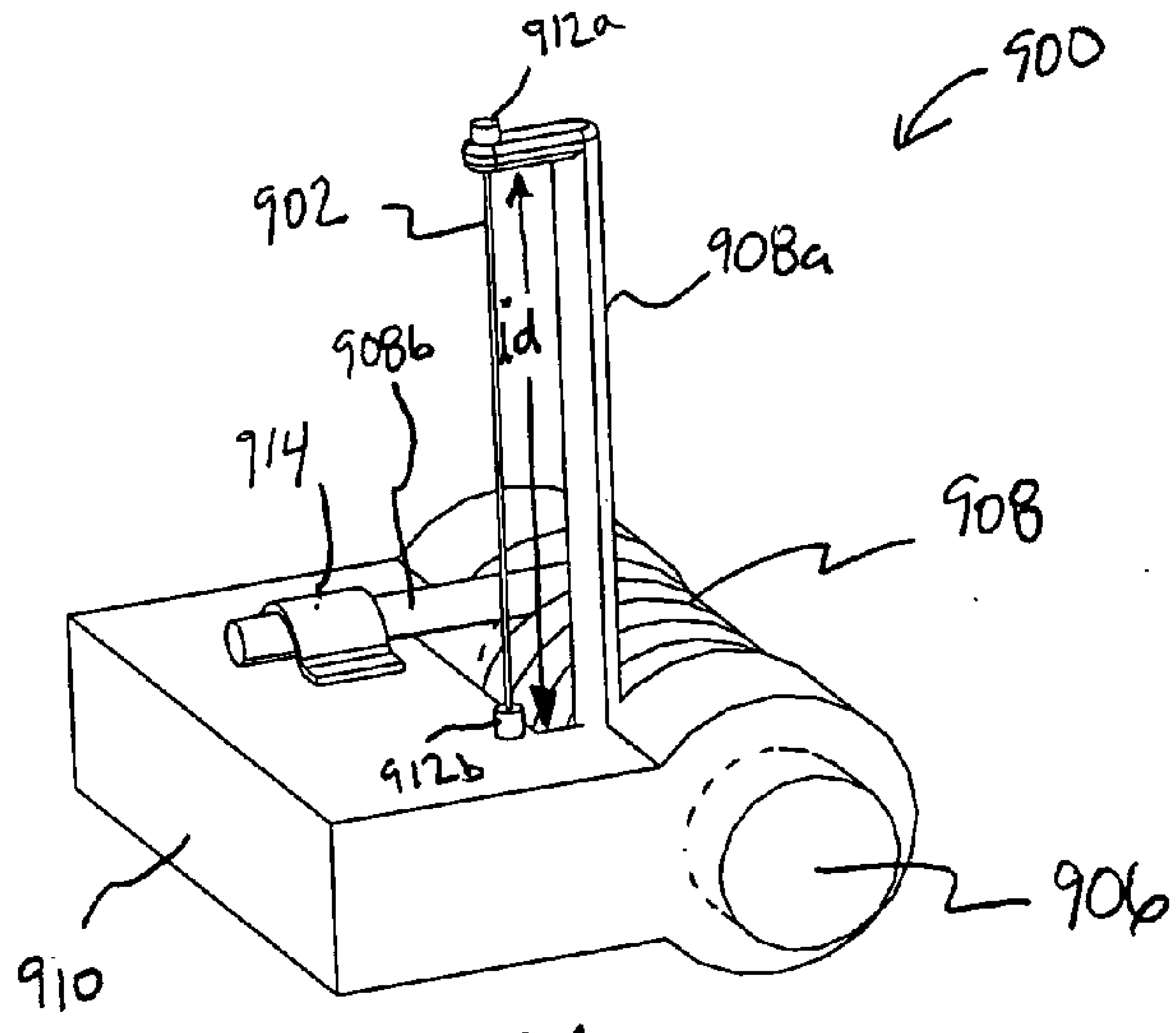


FIG. 9A

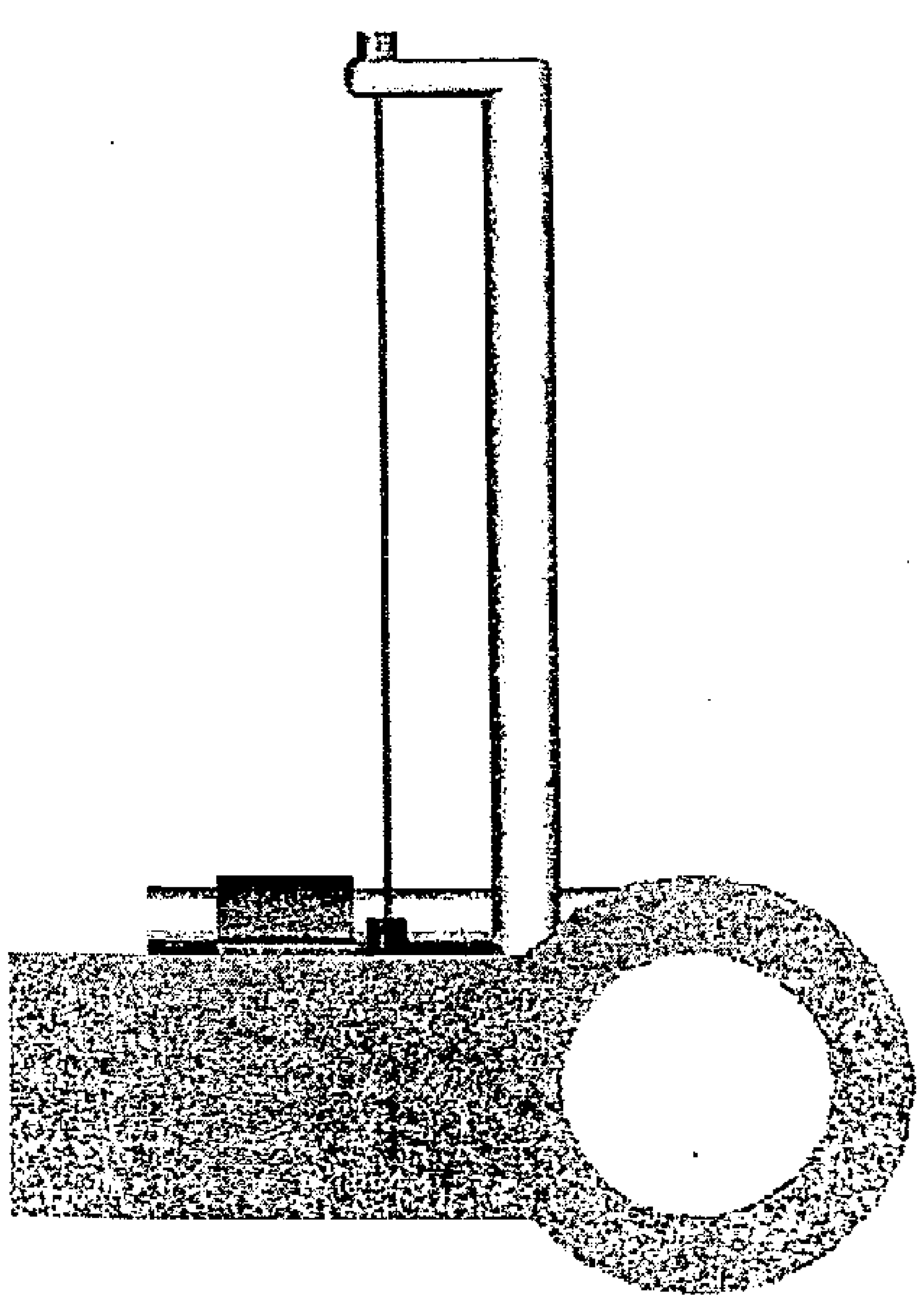


FIG. 9B

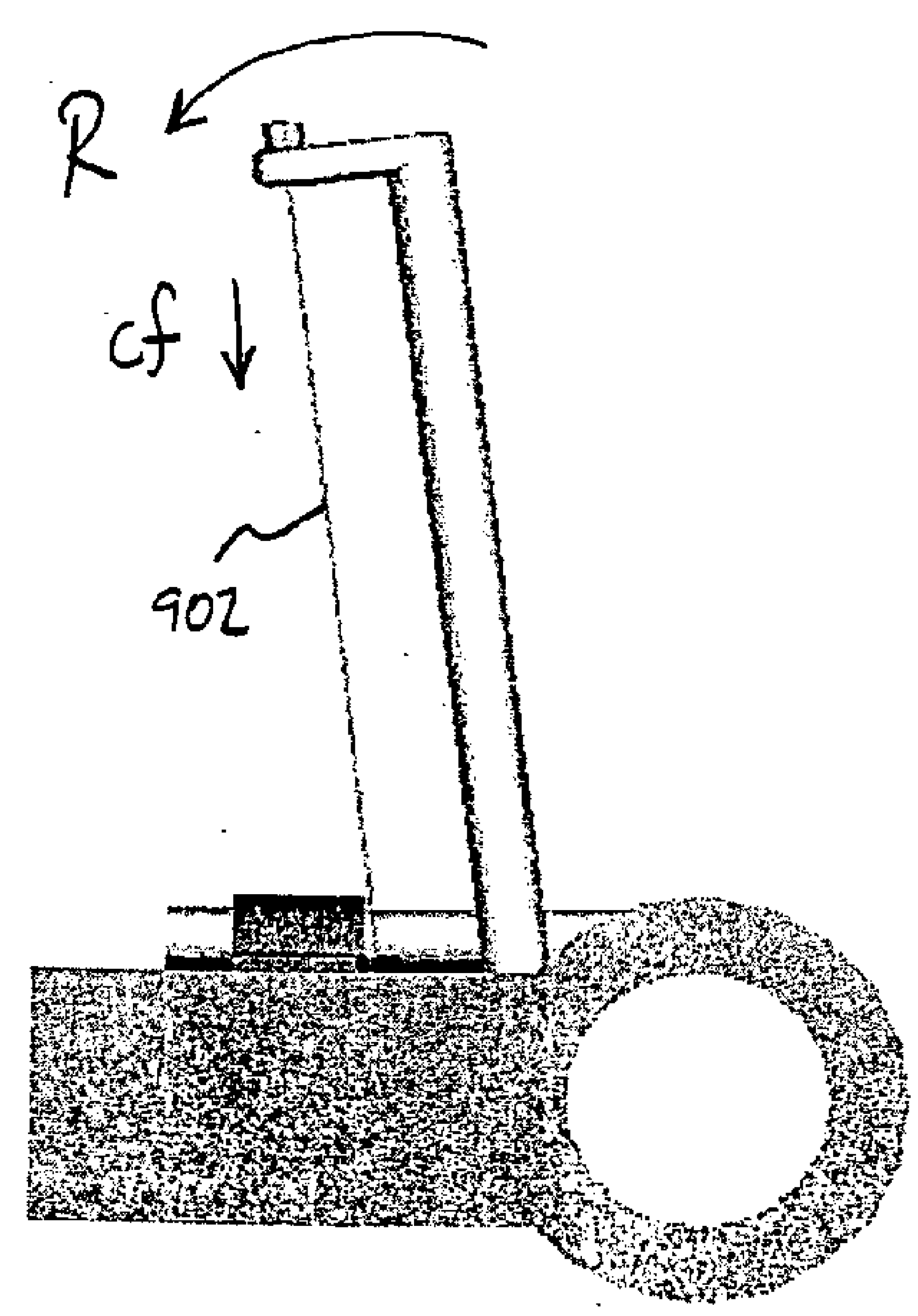


FIG. 9C

SHAPE MEMORY ALLOY-ACTUATED AND BENDER-ACTUATED HELICAL SPRING BRAKES

CROSS REFERENCE TO A RELATED APPLICATION

[0001] This application claims benefit under 35 U.S.C. 119(e) of United States Provisional Patent Application Number 60/484,021 filed Jun. 30, 2003 entitled "SMA-Actuated Helical Spring Brake," the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to braking systems, and in particular, to shape memory alloy ("SMA")-actuated and to bender-actuated helical brake mechanisms for permitting and inhibiting movement of one or more members relative to each other.

BACKGROUND OF THE INVENTION

[0003] Helical wrap springs are commonly employed in conventional braking mechanisms to control whether two or more moveable members can move relative to each other. In a typical helical spring brake, a helical wrap spring is positioned concentrically about, and in frictional engagement with, the outer surface of a drive member, such as a shaft or drum. The direction of the turns of the helical wrap spring permits rotation of the shaft in one direction relative to the spring (i.e., in a direction that tends to unwrap the helically coiled spring), but those same turns also prevent rotation of the shaft in the opposite direction (i.e., in a direction that tends to wrap the helically coiled spring). By externally applying an expansion or separation force to the ends of the spring, the spring operates frictionlessly, or nearly frictionlessly, with respect to the shaft. As such, the shaft is released to freely rotate in either direction relative to the spring.

[0004] Traditionally, actuation mechanisms that expand or separate the spring ends typically rely on a collection of sophisticated linkages (e.g., cables or rods), gears or other relatively complicated mechanical configurations. There are at least as many types of actuation mechanisms for initiating or terminating braking as there are applications for helical spring brakes. Some examples of applications employing helical spring brakes include automobiles, bicycles, elevators, hoists, as well as adjustment mechanisms for window regulators, window shades, car seats, seat head rests, and the like.

[0005] But the conventional actuation mechanisms used to activate braking in these applications, although adequate in operation, are typically associated with one or more of the following drawbacks. A first drawback is that conventional actuation mechanisms usually require either numerous quantities of members (e.g., a number of gears) or large-sized members (e.g., elongated activator members, such as rods or cables), or both, to effectuate actuation. As such, conventional actuators for helical wrap spring brakes are generally suboptimal in form factor (i.e., in physical, external dimensions) as well as in simplicity. As an example, consider that window lifters using a helical spring brake are well known in the art to inhibit unintentional motion of the lifting mechanism (and the window). To inhibit the unintentional motion of a payload (i.e., an object being acted upon, such as a window), lifting mechanisms rely on complex configurations using one or more of the following: a set of gears; concentric drums in which an internal helical wrap spring unwinds from a first drum to engage frictionally with the inner surface of a second drum, which is hollow and co-axial with the first; multiple springs for all directions of travel; a relatively heavy motor having enough friction in its off state so that the payload will remain stationary (such heavy motors typically consume more power than is otherwise necessary); and a pin-like latch for locking a part used to lift a payload, the unlocking of which requires an actuator powerful enough to disengage the pin from the locked part as the weight of the payload (e.g., a window) bears down on the pin.

[0006] Other drawbacks of current helical spring brake actuators are that the use of linkages and gears tend to either limit the placement of a trigger for the actuator or require sufficient physical dexterity by users to trigger actuation (i.e., by manually separating the spring ends), or both. As such, manual separation of the spring ends can be difficult for elderly or otherwise infirm users. For example, automobile parking brakes or hood latches employing helical spring brakes generally require substantial effort to release the helical wrap spring. Moreover, the triggering means to release parking brakes and hood latches, such as a knob, are inconveniently located underneath the steering wheel and dashboard.

[0007] As another example, consider that helical wrap spring actuation mechanisms for seat reclination applications (as well as other applications) typically employ a number of gears or linkages for activating a helical spring brake, which tends to be off-axis to the gears or linkages. This arrangement increases the number of components constituting the actuation mechanism. As with parking brakes and hood latches, a triggering means is used to either recline a seat back or to move the seat forward to enable persons to enter or exit a back seat. An example of such a triggering means is a manual seat latch, which is inconveniently located at the bottom of a seat back, near the floor of a vehicle. So, conventional actuation mechanisms generally limit designers from placing the triggering means in a convenient location. Another drawback is that the mechanical linkages and gears that traditionally constitute these actuators can inadvertently generate audible sounds, as noise, from the interaction of the actuator components.

[0008] In view of the foregoing, what is needed is an improved actuation mechanism for operating helical spring brakes to overcome the drawbacks of conventional actuators.

SUMMARY OF THE INVENTION

[0009] In one embodiment of the present invention, a shape memory alloy ("SMA")-actuated helical spring brake comprises a rotatable member and a helical wrap spring arranged concentrically about the rotatable member. The spring has a first spring end and a second spring end and it includes a number of turns configured to frictionally engage the rotatable member by means of an inwardly-directed radial bias. The turns permit rotation of the rotatable member in a first direction and inhibit rotation in a second direction. The SMA-actuate helical spring brake also includes an anchor point coupled to the second spring end, and an SMA actuator having an output drive member coupled to the first spring end. The SMA actuator is configured to, for example, deflect the first spring end to permit the rotatable member to rotate. The rotatable member is typically a shaft.

[0010] In a related embodiment, the SMA-actuated helical spring brake can include a motor rigidly coupled to the rotatable member for providing a motive torque to rotate the rotatable member. The SMA-actuated helical spring brake can also include a payload rigidly coupled to the rotatable member. In some cases, the payload exerts a bias torque sufficient to rotate the rotatable member in the second direction when the helical wrap spring permits the rotatable member to rotate. As such, this SMA-actuated helical spring brake is suitable to operate on a payload that is a window. In another embodiment, the SMA-actuated helical spring brake further comprises a biasing device configured to induce rotation of the rotatable member in the second direction when the helical wrap spring permits the rotatable member to rotate. Consequently, an SMA-actuated helical spring brake with a biasing device is suitable to operate on a pin-latch mechanism, a door opening mechanism or a seat back safety lock release mechanism. In some embodiments of the present invention, a bender actuator is substituted for an SMA actuator to govern actuation of a helical spring brake.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The invention is more fully appreciated in connection with the following detailed description taken in conjunction with the accompanying drawings, in which:

[0012] **FIG. 1** depicts a shape memory alloy ("SMA")-actuated helical spring brake, according to one embodiment of the present invention;

[0013] **FIGS. 2A and 2B** respectively depict a deflection detector and a rotation detector for controlling SMA-actuated helical spring brakes, according to one embodiment of the present invention;

[0014] **FIG. 3** depicts a helical spring brake employing an energy storage device as a bias force in accordance with an embodiment of the present invention;

[0015] **FIG. 4** illustrates an implementation of an SMA-actuated helical spring brake of **FIG. 1** in a window lifting mechanism, according to one embodiment of the present invention;

[0016] **FIGS. 5 and 6** are axial views illustrating an implementation of the SMA-actuated helical spring brake of **FIG. 3** in a pin-latch release mechanism, according to an embodiment of the present invention;

[0017] **FIG. 7** illustrates another implementation of an SMA-actuated helical spring brake of **FIG. 3** in a door mechanism, according to at least one embodiment of the present invention;

[0018] **FIG. 8** is a functional block diagram of a vehicle seat back release mechanism implementing an SMA-actuated helical spring brake in accordance with an embodiment of the present invention; and

[0019] **FIGS. 9A** to **9C** illustrate a bender-actuated helical spring brake in accordance with an embodiment of the present invention.

[0020] Like reference numerals refer to corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0021] Embodiments of the present invention relate to SMA-actuated and bender-actuated helical spring brakes for imparting motion to a payload. According to some embodiments of the invention, an SMA-actuated helical spring brake can be configured to permit or inhibit a rotatable member to move a payload, such as window, a seat back, etc. Advantageously, an SMA-actuated helical spring brake according to some embodiments of the present invention can be formed with a relatively compact form factor so as to preserve space that otherwise would be consumed by sophisticated linkages, gears or other relatively complicated mechanical configurations. As such, embodiments of the present invention facilitate the miniaturization of helical spring brake actuator mechanisms. Without the need for physical efforts to release a helical spring brake in accordance to some embodiments, SMA-actuated helical spring brakes facilitate actuation for elderly and infirm users. Also, an SMA-actuated helical spring brake according to some embodiments of the present invention can be triggered remotely without requiring mechanical linkages from the site of remote activation to the brake, thus allowing convenient placement of a trigger for activating SMA-actuated helical spring brakes. Moreover, an SMA-actuated helical spring brake according to some embodiments of the present invention can include a deflection detector or a rotation detector to reduce the amount of time that an SMA actuator remains activated, thus increasing the life expectancy of the SMA actuator.

[0022] **FIG. 1** depicts a shape memory alloy ("SMA")-actuated helical spring brake **100**, according to one embodiment of the present invention. Helical spring brake **100** includes an SMA actuator **102**, a helical wrap spring **108** and an immovable anchor point **114** for permitting or inhibiting rotation of a shaft **106**. SMA actuator **102** is coupled to helical wrap spring **108** at spring end (or tang) **108*a*** for controlling whether helical wrap spring **108** frictionally engages shaft **106** to govern the rotational motion of shaft **106**. Further, helical wrap spring **108** is coupled to anchor point **114** at another spring end **108*b***. Also, shaft **106** is rigidly coupled to a motor **104** and a payload **110**.

[0023] A trigger **101** is configured to trigger activation of SMA actuator **102**, which in turn releases helical spring brake **100**. Trigger **101**, such as a push-button, can be located at a location convenient to a user without regard to linkages, gears, or some other mechanical member extending from trigger **101** to SMA-actuated helical brake, as typically required by conventional helical wrap spring actuation mechanisms. Trigger **101** generates an electrical signal that causes SMA actuator **102** to activate.

[0024] SMA actuator **102** can be of any configuration that uses one or more SMA elements as the primary force generation means. An SMA "element" refers to an SMA material of elongate form, capable of contraction and elongation along the longitudinal axis. The element may have a circular cross-section, as is the case for an SMA wire, or any of a variety of cross-sections such as elliptical, square, rectangular, or the like. Shape memory alloy ("SMA") refers to metals, which exhibit two very unique properties, pseudo-elasticity, and the shape memory effect. Pseudo-elasticity refers to the almost rubber-like flexibility of SMAs. The shape memory effect refers to the unique ability of shape memory alloys to be severely deformed and then returned to their original shape simply by heating them. By way of example and not limitation, shape memory alloys include NiTi (Nickel-Titanium), CuZnAl, and CuAlNi among others. Although other means are known in the art, heating is commonly accomplished by passing an electric current through the wire. For purposes of concreteness, the description of the present invention invokes mainly electric or ohmic heating of the SMA wire.

[**0025**] To effectuate actuation of SMA actuator **102**, its SMA elements (e.g., SMA wires) are heated by passing a current through the elements, causing an output drive member **103** of SMA actuator **102** to retract. Output drive member **103** is typically a plate, rod, or some other member configurable to drive a load upon which SMA actuator **102** operates. A perspective view of output driver member **103** is shown in **FIGS. 2A and 2B** as output drive member **203**. By contrast, when the SMA elements of SMA actuator **102** are cooled, SMA actuator **102** and its output drive member **103** can return to its extended state. The return to the extended state may be accomplished by a number of methods. In **FIG. 1**, it is accomplished by using the resilience of helical wrap spring **108** and its spring ends **108***a* and **108***b* to create a spring bias. Alternatively, another spring may be added to increase the bias force by cooperating with the bias of helical wrap spring **108**. Yet another alternative results when another actuator is used to extend SMA actuator **102**. The another actuator may itself be based on SMA elements or maybe of a completely different nature. Without undue effort, an ordinarily skilled artisan should appreciate that SMA actuator **102** can be designed to drive a wide range of loads. That is, SMA actuator **102** can be adapted to be able to move the spring ends of most types of helical wrap springs (e.g., from light-duty springs to heavy-duty springs). In accordance with a specific embodiment of the present invention, SMA actuator **102** can be a single or multiple-strand SMA wire, or it can be any actuator disclosed in U.S. Pat. No. 6,574,958 having a title "Shape Memory Alloy Actuators and Control Methods," which is incorporated herein by reference in its entirety. That patent was filed on Aug. 11, 2000 and is assigned to NanoMuscle, Inc.

[**0026**] Motor **104** is a drive mechanism for rotating shaft **106**. The drive mechanism can operate by converting electrical energy, mechanical energy, thermal energy, or some other type of energy into mechanical energy for imparting a rotational force upon shaft **106**. In some embodiments, motor **104** operates to turn shaft **106** in one direction of rotation while payload **110** tends to cause shaft rotation in the other direction. In some cases, motor **104** can be a motive force provided by a human being (i.e., a person causes rotation of shaft **106**). Payload **110** is the object that helical spring brake **100** operates upon via shaft **106** to either permit that object to move or to inhibit its motion. Examples of such objects include windows, window regulators, window shades, car seats, seat head-rests, latches, vehicle power door locks, power glove-box locks, gas-tank flaps, trunk lids, or any other type of object where it is desirable to control the motion of that object. In some cases, payload **110** provides its own bias force that biases rotation of shaft **106** in direction D1. For example, if payload **110** is a window, gravity acting on the mass of the window is the bias force for that window.

[**0027**] Helical wrap spring **108** is configured to maintain frictional engagement with shaft **106** when spring end **108***a* is not being acted upon by SMA actuator **102**. Specifically, when SMA actuator **102** is in its extended state (i.e., inactive or unpowered), helical wrap spring **108** remains firmly wrapped in a direction around shaft **106** such that if the bias of payload **110** causes rotation of shaft **106**, the frictional engagement between shaft **106** and helical wrap spring **108** strengthened. As such, payload **110** cannot rotate in direction "D1." But when SMA actuator **102** is in its contracted state (e.g., when it is triggered or activated by a user), output drive member **103** of SMA actuator **102** acts upon spring end **108***a* to deflect it by an amount that tends to unwrap spring **108** from shaft **106**. This deflection permits helical wrap spring **108** to operate in frictionless engagement with shaft **106** so that shaft **106** is free to rotate in either direction "D1" or "D2."

[**0028**] In accordance with various embodiments of the present invention, helical spring brake **100** provides a braking mechanism regardless of whether motor **104** is found in any of three states. In a first state, motor **104** is unpowered and does not engage or rotate shaft **106**. In a second state, motor **104** is configured to rotate shaft **106** against the bias of payload **110**. And in a third state, motor **104** is configured to rotate shaft **106** in the same direction as the bias of payload **110**.

[**0029**] In the first state, consider that motor **104** and SMA actuator **102** are both inactive. In this state, the bias of payload **110** can cause shaft **106** to begin rotating if helical wrap spring **108** is not sufficiently engaged with shaft **106**. Because of the orientation of the wrapped turns of helical wrap spring **108**, friction between shaft **106** and helical wrap spring **108** acts to wind the latter more tightly around the former until rotational movement of shaft **106** ceases completely. Helical wrap spring **108** can be configured so that its winding about shaft **106** is almost imperceptible and its response time is almost instantaneous when braking has been initiated.

[**0030**] In the second state, consider that SMA actuator **102** is inactive (i.e., in an extended and slack state) and motor **104** is active or powered to rotate shaft **106**. Motor **104** drives shaft **106** to slightly unwind helical wrap spring **108** in direction D2, thereby significantly reducing the friction between shaft **106** and helical wrap spring **108**. Thereafter, the load presented to motor **104** is primarily that of payload **110**. So to rotate shaft **106** in direction D2, the torque output of motor **104** should exceed the torque load of payload **110**. Once the torque generated by motor **104** surpasses that of the torque load of payload **110** by an amount at least equal to the residual frictional torque of helical wrap spring **108** about shaft **106**, shaft **106** rotates in direction D2. For example, consider that payload **110** is a window. Once motor **104** generates enough torque to overcome the weight of the window (as a bias) and the slight residual friction of helical wrap spring **108**, the window will move from a rolled-down position to a rolled-up position.

[**0031**] In the third state, consider that SMA actuator **102** is active and in a state of contraction, whereas motor **104** is inactive (i.e., unpowered). In this state, SMA actuator **102** moves spring end **108***a* in an unwinding direction. This movement causes the frictional force exerted by helical wrap spring **108** on shaft **106** to be significantly reduced. If the bias of payload **110** is sufficient to overcome other frictional torques of the system (e.g., that of an unpowered motor **104**), then shaft **106** rotates in direction D1. Continuing with the previous example, the weight of the window as payload **110** causes the window to move from a rolled-up position to a rolled-down position. In some embodiments, motor **104** can be activated in this state to urge movement of payload **110** if the bias of payload **110** is insufficient to overcome the frictional forces in the system or if greater speed is desired.

[**0032**] **FIGS. 2A and 2B** respectively depict a deflection detector and a rotation detector for controlling SMA-actuated helical spring brakes, according to embodiments of the present invention. **FIG. 2A** shows an exemplary helical spring brake **200** including SMA actuator **102** and deflection detector **202** for controlling deflection of helical wrap spring **108**. SMA actuator **102** is affixed to an immovable anchor point **201** so that output drive member **203** of SMA actuator **102** can drive spring end **108***a*. Output drive member **203** of SMA actuator **102** can be an extension rod or any other coupling element suitable to pull (or push) spring end **108***a* to deflect that end by a distance, "d." In one embodiment, the length "l," of spring end **108***a* is adapted to provide an appropriate amount of leverage so that an SMA-based actuator, such as SMA actuator **102**, can actuate helical spring brake **200**.

[**0033**] Deflection detector **202** is communicatively coupled to SMA actuator **102**, and is configured to detect when spring end **108***a* deflects by the distance, d, from a first position, "P1," to a second position, "P2." Position P1 indicates the position of spring end **108***a* at which helical wrap spring **108** frictionally engages shaft **106** to inhibit rotation, whereas position P2 indicates the position of spring end **108***a* at which shaft **106** freely rotates. Deflection detector **202** can include a wiper **205** configured to maintain contact with output drive member **203** as it retracts and extends. Wiper **205** sends a signal indicating contact with either point **202***a* or point **202***b*. Point **202***a* is coincident with the beginning of travel for output drive member **203** as well as position P1, and point **202***b* is coincident with the end of travel for output drive member **203** as well as position P2. Given this, deflection detector **202** permits SMA actuator **102** to operate between a beginning and an end of travel respectively coincident with position P1 and position P2.

[**0034**] In operation, spring end **108***a* typically starts at position P1. Deflection detector **202** will indicate this position to SMA actuator **102**. When a user triggers SMA actuator **102**, output drive member **203** moves spring end **108***a* to position P2 as SMA actuator **102** contracts. A suitable trigger can be a push button conveniently accessible to a user, or the trigger can be any other mechanism for closing an electrical circuit so that current will pass through the SMA elements of SMA actuator **102**. When deflection detector **202** detects point **202***b* (i.e., end of travel has been reached, spring end **108***a* is at position P2), then SMA actuator **202** powers down its SMA wires so as not to overheat them. A suitable circuit for practicing one embodiment of deflection detector **202** in accordance with the present invention is disclosed in U.S. patent application Ser. No. 10/080,640, titled "SMA Actuator with Improved Temperature Control" and filed on Feb. 21, 2002, the disclosure of which is incorporated herein by reference in its entirety. In some embodiments, SMA-actuator **102** powers its SMA elements for a duration of time necessary to deflect spring end **108***a* from P1 to P2, after which deflection detector **202** powers down those SMA elements. So, even if an obstruction hinders deflection of spring end **108***a*, the SMA wires of SMA actuator **102** will not overheat.

[**0035**] In some embodiments, an end-of-travel switch may be conveniently located to detect the movement of the actual payload. Specifically, an end-of-travel having a similar structure to deflection detector can operate to detect a position indicating the end of movement for a payload. In the case of a window lifter mechanism, for instance, such a switch might detect the arrival of the window to its fully lowered position. Also, a power circuit (not shown) can be configured using conventional design techniques to disable its power so that any further triggering (e.g., push-button depression) at trigger **101** by a user will not cause any additional power to flow to the SMA actuator, thereby preserving the longevity of the SMA elements of SMA actuator **102**, among other things.

[**0036**] **FIG. 2B** is another exemplary helical spring brake **250** in accordance with a specific embodiment of the present invention. Helical spring brake **250** includes a rotation detector **254** for controlling operation of SMA actuator **102**. Rotation detector **254** operates to control the powering of SMA elements to either extend or retract output drive member **203** based on whether shaft **106** is rotating, rather than based on an amount of deflection of spring end **108***a*. SMA actuator **102** is coupled to rotation detector **254**, which is configured to detect whether shaft **106** is rotating, and in some cases, the rate at which shaft **106** is rotating. In this example, rotation detector is an optical detector that transmits light and receives light reflected from reflective surfaces **252**, each of which can be reflective tape located equidistant around the outer surface of shaft **106**. Since gaps **256** do not reflect light, rotation detector **254** can detect that shaft **106** is rotating when either reflected light received at a first point in time fades in intensity as the transmitted light becomes incident on a gap **256** at a second point of time, or vice versa.

[**0037**] After SMA actuator **102** is triggered to release helical wrap spring **108**, output drive member **203** begins retracting to deflect spring end **108***a* from position P1 to position P2. In one embodiment, SMA actuator **102** deflects spring end **108***a* relatively quickly so shaft **106** begins rotating expeditiously. Rotation detector **254** detects rotation of shaft **106** and permits SMA actuator **102** to continue operation, without regard to the rate of rotation, until shaft **106** stops rotating. Once rotation detector **254** detects no rotation, it will disable current from being applied through the SMA elements. As shaft **106** rotates in the other direction, rotation detector **254** is configured to determine whether SMA actuator **102** was powered before rotation begins. If it was not powered before shaft **106** begins rotation, then rotation detector **254** refrains from powering the SMA elements of SMA actuator **102**. This means the shaft is rotating in a direction opposite than before. In another embodiment, rotation detector **254** is configured to detect a specific rate of rotation (or a range of rates of rotation) and modulates the passage of current into SMA actuator **102** to maintain shaft **106** rotating at a desired rate of rotation, until shaft **106** ceases rotation. A variety of other sensors and signals may also be configured to control the flow of power to the SMA actuator. For instance, a window lift end-of-travel switch may work in conjunction with rotation detector **254**. In this case, if the rotation stops before the end-of-travel switch is triggered, an unsafe condition may be inferred (such as due to a trapped human limb), and power to the motor may be interrupted to curtail the unsafe situation. A similar condition may be concluded based of reading the signal from a load cell mechanically placed in series between the motor and the window.

[0038] **FIG. 3** depicts a helical spring brake **300** employing an energy storage device **302**, according to one embodiment of the present invention. Helical spring brake **300** is suitable to implement in applications where payload **110** is not sufficiently biased, for example, by its own weight (i.e., its mass under influence of gravity). Without such a bias, helical spring brake **300** requires an external energy storage device **302** to bias shaft **106** in a direction of rotation so that shaft **106** will rotate when helical wrap spring **108** is unwound. Examples of energy storage device **302** are an extension spring, a torsion spring, or some other type of mechanism capable of applying a bias to shaft **106**.

[0039] **FIG. 4** illustrates an implementation of helical spring brake **100** of **FIG. 1** in a window lifting mechanism, according to an embodiment of the present invention. Window lifting mechanism **400** includes a helical spring brake composed of SMA actuator **402**, helical wrap spring **408** an anchor point **414**. The helical spring brake is configured to prevent a window (not shown) from back-driving window lifter member **410** due to the bias of the window. As such, the helical spring brake provides a braked window lifter mechanism **400**, wherein the brake is responsive to a relatively small, light, inexpensive and reliable actuator based on the principles of shape memory alloy ("SMA") actuation. Window lifting mechanism **400** is relatively simple in its construction and can effectuate large changes in frictional force induced by relatively small movements of actuated spring end **408***a*.

[0040] Window lifting mechanism **400** operates as follows. When SMA actuator **402** is inactive with its output drive member **403** extended and slack, helical wrap spring **408** is an frictional engagement with shaft **406**. Helical wrap spring **408** is coupled at spring end **408***a* to output drive member **403** and is coupled at spring end **408***b* to anchor point **414**. With the direction of the wrapped turns of helical wrap spring **408** shown in **FIG. 4**, shaft **406** is relatively free to rotate in direction D2 when driven by motor **404**. As motor **404** rotates shaft **406** in direction D2, window lifter member **410** causes the window, as a payload, to move toward a rolled-up position. When motor **404** stops rotating shaft **406**, the configuration of helical wrap spring **406** prevents shaft **406** from rotating in direction D1. But when SMA actuator **402** is triggered, or activated, then output drive member **403** moves in the direction of retraction, "Q," as shown in **FIG. 4**, which in turn releases helical wrap spring **408**. Optionally, motor **404** can be activated to rotate shaft **406** in direction D1 to lower the window toward a rolled-down position.

[0041] **FIGS. 5 and 6** are axial views illustrating an implementation of helical spring brake **300** of **FIG. 3** in a pin-latch release mechanism, according to embodiments of the present invention. **FIG. 5** shows pin-latch release mechanism **500** implementing an SMA-actuated helical spring brake suitable for applications where a payload lacks sufficient bias to rotate shaft **512**. Examples of suitable applications are security devices, such as door locks, furniture locks, automotive components, such as glove boxes, trunk lids, hood latches, parking brake releases, and many other types of uses. In the example shown in **FIG. 5**, a pin **504**, as a payload, is engaged with a locking recess, or latch **502**. The helical spring brake of pin-latch release mechanism **500** includes SMA actuator **520** affixed to an immovable anchor point **524**, helical wrap spring **514**, pin **504**, a link member **506** and a bias device **508**.

[0042] **FIG. 5** depicts helical wrap spring **514** being frictionally engaged with shaft **512**, and having a first spring end **514***b* coupled to output drive member **522** and a second spring end **514***a* immobilized by anchor point **516**. Spring end **514***b* is in position P1 when SMA actuator **524** is inactive so that output drive member **522** remains extended. Further to **FIG. 5**, link member **506** is pivotally coupled to pin **504** and to bias device **508**. Bias device **508** is shown as an extension spring having another end affixed to anchor point **510**. Link member **506** is rigidly coupled to shaft **512** to rotate in the same direction and by the same amount as shaft **512**. Extension spring **508** is extended so as to provide a bias force, "f," toward anchor point **510** that is sufficient to rotate both link member **506** and shaft **512**. But with helical wrap spring **514** wrapped in a manner around shaft **512** such that the bias force, f, pulls shaft **512** in a wrapping direction of helical wrap spring **514**, shaft **512** maintains frictional engagement with helical wrap spring **514**. This prevents pin **504** from disengaging latch **502**.

[0043] **FIG. 6** depicts pin-latch release mechanism **500** after SMA actuator **520** actuates to release the helical spring brake. Once SMA actuator is active, output drive member **522** retracts to move spring end **514***b* to position P2, which is in the unwind direction. At position P2, shaft **512** freely rotates along with link member **506**. Under bias force, f, link member **506** rotates toward anchor point **510** thereby disengaging pin **504** from latch **502**. As such, a first member (not shown) associated with latch **502**, such as car hood, is moveable in relationship to a second member (not shown) associated with pin **504**, such as a car frame. In some embodiments, a user provides a motive force (not shown) to rotate shaft **512** and to reextend extension spring **508** by manually moving (or by other means) the first member back into engagement with the second member, which concurrently stores potential energy in extension spring **508** for the next activation of SMA actuator **520**.

[0044] **FIG. 7** illustrates another implementation of helical spring brake **300** of **FIG. 3** in a door or lid moving mechanism, according to an embodiment of the present invention. **FIG. 7** shows door-moving mechanism **700** having a payload that lacks sufficient bias to rotate shaft **707** of the SMA-actuated helical spring brake. In the example shown in **FIG. 7**, a door **702** (e.g., a glove box door) is the payload, a portion of which is shown in **FIG. 7**. The helical spring brake of door-moving mechanism **700** includes SMA actuator **704** affixed to an immovable anchor point (not shown), helical wrap spring **708**, and a torsion spring **720** as a bias device. Helical wrap spring **708** is frictionally engaged with shaft **707**, having a first spring end **708***a* coupled to output drive member **706** and a second spring end **708***b* immobilized by anchor point **714**. Torsion spring **720**, or its equivalent, is employed to provide a bias force, T, in the direction shown. When SMA actuator **704** is inactive and glove box door **702** is in its closed position, as shown schematically by a dashed line, helical wrap spring **708** precludes glove box door **702** from moving into its open position until SMA actuator **704** is energized. When activated, SMA actuator **704** causes output drive member **706** to retract in direction, "CD," so as to unwrap spring end **708***a*. This permits shaft **707** to rotate glove box door **702** to its open position (shown in the figure) under the influence of torsion spring **720**. As glove box door **702** is closed by a user from its open position, potential energy is once again stored in torsion spring **720** for future use. It should be noted that the positions designating an "open" position and a "closed" position can be interchanged. Door-moving mechanism **700** merely specifies an application that requires a bias assist torque be released at will, or remotely, to rotate a door-like object from one position to another. The two positions would then be described as corresponding to a charged and a discharged state of the energy storage component **302**, as shown abstractly in **FIG. 3**.

[**0045**] **FIG. 8** is a functional block diagram of a vehicle seat back release mechanism implementing a helical spring brake in accordance with an embodiment of the present invention. In most vehicles, such as automobiles, some seats are designed to recline or to move (or tilt) forward to permit passengers to enter and exit a back seat. For safety reasons, automobile seats capable of tilting forward require safety interlocks capable of withstanding the likely disturbances encountered by automobiles that otherwise might cause inadvertent tilting or reclining in the event of sudden deceleration. In two-door cars, access to the back seat requires a front seat to easily adjust to a forward tilt position while being manipulated by a back-seat passenger. In accordance with the present invention, an SMA actuated-helical spring brake is implemented in a vehicle seat back release mechanism **800**, and therefore, facilitates comfortable access to rear seating areas of a vehicle, especially for the increasing numbers of elderly and infirm passengers. Specifically, the seat back release can be a simple button that is conveniently located in a general area, such as on the back of a seat.

[**0046**] Vehicle seat back release mechanism **800** includes an SMA-actuated helical spring brake composed of SMA actuator **802**, helical wrap spring **808** and anchor member **828**. Helical wrap spring **808** frictionally engaged with shaft **806** when SMA actuator **802** is inactive, and has a first spring end **808***a* coupled to an output drive member of SMA actuator **802** and a second spring end **808***b* anchored at anchor member **828**. SMA actuator **802** and anchor member **828** are rigidly coupled to seat back **804**. Seat back **804** can be viewed as a motor that provides a motive torque to vehicle seat back release mechanism **800**. A human hand typically applies the motive torque applied to seat back **804**.

[**0047**] Shaft **806** is rigidly coupled to coupling **820** and energy storage device **830**. In this example, energy storage device **830** is a torsion spring for storing potential energy. Torsion spring **830** is thus configured to provide a bias torque to shaft **806** when helical wrap spring **808** is released. The bias torque from torsion spring **830** is designed to operate upon coupling **820**, which is the previously-described payload. Coupling **820** engages a lock release **822** that is configured to release safety lock **824**. Safety lock **824** prevents inadvertent movement of seat back **804**, especially during moments of extreme deceleration.

[**0048**] Vehicle seat back release mechanism **800** operates as follows. First, consider that seat back **804** is in an upright position and safety lock **824** is locked to prevent inadvertent forward or rearward movement of seat back **804**. Also, torsion spring **830** has already been charged upon previously rotating seat back **804** from a forward position to the upright position in direction "charge"**832**. Typically, the bias torque of torsion spring **830** is generated by human hand. This bias force causes shaft **806** to rotate against the turns of helical wrap spring **808**, thereby causing helical wrap spring **808** to be in its extra wrapped state. As such, torsion spring cannot discharge while shaft **806** is in frictionally engaged.

[**0049**] To enter or exit rear seat, a passenger triggers or activates SMA actuator **802** to cause helical wrap spring **808** to unwrap slightly so as to release its grip on shaft **806**. When helical wrap spring **808** releases shaft **806**, the bias torque from torsion spring **830** causes coupling **820** to disengage lock release **822**, thereby causing safety lock **824** to unlock. Since unlocking of safety lock **824** permits relative rotation between seat back **804** and shaft **806**, the bias torque from torsion spring **830** does not itself affect the position of seat back **804**.

[**0050**] When a user tilts seat back **804** in a forward direction for entry or exit, anchor member **828**, which is firmly attached to seat back **804**, follows along in unison. The unwrapping action expected primarily at spring end **808***b*, however slight, permits a relative rotation of both seat back **804** and helical wrap spring **808** about shaft **806**, which remains stationary. Although SMA actuator **802** can be typically inactive with its output drive member relaxed or extended during the forward movement of seat back **804**, SMA actuator **802** can optionally be activated to reduce friction with shaft **806**.

[**0051**] Next, when a user again brings seat back **804** to an upright position, the wrapping action of the coil of helical wrap spring **808** at end **808***b* causes it to frictionally engage shaft **806**. SMA actuator is unpowered during the return of seat back **804** to its upright position. So, as seat back **804** continues moving to its upright position, shaft **806** transfers torque to recharge torsion spring **830**. Then, coupling **820** returns to its initial state of engaging lock release **822**. Once seat back **804** is returned it its upright position, safety lock **824** moves in direction "reset"**826** to again lock seat back **804** against inadvertent seat back movement.

[**0052**] **FIGS. 9A** to **9C** illustrate a bender-actuated helical spring brake in accordance with an embodiment of the present invention. Helical wrap spring **908** has a first spring end **908***a* configured to extend as a lever arm, and also has a second spring end **908***b* immovably secured at anchor point **914**, which is affixed to support **910**. Support **910** provides general support for shaft **906** so that it can rotate. Further, support **910** can internally include electrical and mechanical mechanisms (not shown) to power actuator **902**. Actuator **902** can include one or more actuation elements composed of SMA wires and/or bender actuators. Insulators **912***a* and **912***b* allow actuator **902** to remain electrically and mechanically isolated from support **910**. **FIG. 9B** shows actuator **902** in one state and **FIG. 9C** shows actuator **902** in another state, such as its active state. That is, when actuator **902** contracts in the direction of retraction force, "cf," first spring end **908***a* moves in direction "R."

[0053] Bender actuators are well known and are constructed from any of several technologies, such as piezoelectric, bi-metal (thermally bendable), as well as SMA actuators. Bender actuators typically consist of two elongated members joined mechanically either at both ends, or entirely along their common length. Generally, the two members differ in their responsiveness to external stimuli. For instance, in a piezoelectric bender actuator, one member can be a piece of active ceramic whereas the other is a passive element. The passive element can be any of the following: a passive ceramic, a passive metal, or an active ceramic, but with opposite sign of responsiveness. When an appropriate stimulus is applied to a bender actuator as actuator **902**, bender actuator either bends or tilts (i.e., does not necessarily contract or expand linearly). For example, if actuator **902** is a bender actuator, then it has one end fixed to support **910** via insulator **912***b*. The other end of actuator **902** is coupled to first spring end **908***a* via insulator **912***a*. As such, the bender actuator is able to perform mechanical work, even though it can generate forces along a curved path that is generally perpendicular to the long direction of actuator **902**. Conceptually, first spring end **908***a* of actuator **902** can be viewed as being part of actuator **902**, when configured as a bender actuator.

[0054] Regardless, the bending action inherent in bender actuators works by deflecting the movable end (i.e., first spring end **908***a*) in a direction that unwraps the coil of helical wrap spring **908**. This action advantageously includes both an angular tilt component and a small tangential translation component of first spring end **908***a*. Both of these components work in the direction of unwrapping helical wrap spring **908**. The balance between the tilt and translation components depends on the initial distance, "id," from a connection point associated with insulator **912***b* to a connection point associated with insulator **912***a*. The availability of both of these components means that distance "id" need not be set with excessively tight tolerance. This, in turn, makes the manufacturability of products more forgiving of assembly inaccuracies.

[0055] The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that specific details are not required in order to practice the invention. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed; obviously, many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain the principles of the invention and its practical applications, they thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. Any feature of any specific embodiment of the present invention can be employed in any embodiment described herein. It is intended that the following claims and their equivalents define the scope of the invention.

1. A shape memory alloy ("SMA")-actuated helical spring brake comprising:

a rotatable member;

a helical spring brake having a first spring end and a second spring end; and

an SMA actuator having an output drive member coupled to said first spring end and configured to deflect said first spring end to permit said rotatable member to rotate,

wherein said SMA actuator is configured to

retract said output drive member to move said first spring end from a first position to a second position when sufficient power is applied to said SMA actuator, and to

extend said output drive member as said first spring end moves from said second position to said first position when power is removed from said SMA actuator.

2. The SMA-actuated helical spring brake of claim 1 wherein said helical spring brake comprises:

a helical wrap spring arranged concentrically about said rotatable member and having said first spring end and said second spring end, said helical wrap spring including a number of turns that are biased radially inward and are configured to frictionally engage said rotatable member, said turns permitting rotation of said rotatable member in a first direction and inhibiting rotation in a second direction; and

an anchor point coupled to said second spring end.

3. The SMA-actuated helical spring brake of claim 1 further comprising a trigger to generate an electrical signal for a predetermined duration that causes said SMA actuator to contract by heating one or more SMA elements.

4. The SMA-actuated helical spring brake of claim 3 wherein said trigger is configured to require less physical effort by a user than a mechanically-actuated helical spring brake.

5. The SMA-actuated helical spring brake of claim 2 further comprising a deflection detector configured to detect said first spring end moving from a first position to a second position, wherein at said first position said helical wrap spring is frictionally engaged with said rotatable member and at said second position said helical wrap spring permits said rotatable member to rotate in either direction.

6. The SMA-actuated helical spring brake of claim 5 wherein said deflection detector is further configured to deactivate said SMA actuator to increase longevity of said SMA actuator upon detecting said second position.

7. The SMA-actuated helical spring brake of claim 2 further comprising a rotation detector configured to detect whether said rotatable member is rotating.

8. The SMA-actuated helical spring brake of claim 7 wherein said rotation detector is configured to stop said output drive member from retracting to increase longevity of said SMA actuator upon detecting that said rotatable member stops rotating.

9. The SMA-actuated helical spring brake of claim 7 wherein said rotation detector is configured to control the rotation of said rotatable member at a relatively steady rate of rotation.

10. The SMA-actuated helical spring brake of claim 2 further comprising:

a motor rigidly coupled to said rotatable member for providing a motive torque to rotate said rotatable member; and

a payload rigidly coupled to said rotatable member.

11. The SMA-actuated helical spring brake of claim 10 further comprising an end-of-travel switch configured to detect an end-of-travel position for said payload and to deactivate said SMA actuator upon detecting said end-of-travel position to increase longevity of said SMA actuator.

12. The SMA-actuated helical spring brake of claim 10 wherein said payload has a bias force sufficient to rotate said rotatable member in said second direction when said helical wrap spring permits said rotatable member to rotate.

13. The SMA-actuated helical spring brake of claim 12 wherein said payload is a window.

14. The SMA-actuated helical spring brake of claim 10 further comprising a biasing device configured to induce rotation of said rotatable member in said second direction when said helical wrap spring permits said rotatable member to rotate.

15. The SMA-actuated helical spring brake of claim 14 wherein said payload is either a pin of a pin-latch mechanism or a door of a door-moving mechanism.

16. A shape memory alloy ("SMA")-actuated system for imparting motion to a payload comprising:

a rotatable member configured to cause said payload to move; and

an SMA-actuated helical spring brake in frictional engagement with said rotatable member when said SMA-actuated helical spring brake is inhibiting rotation of said rotatable member in at least one direction, thereby preventing movement of said payload in said at least one direction,

wherein said SMA-actuated helical spring brake is configured to release said rotatable member to freely rotate when power is applied to sufficiently contract one or more SMA elements of said SMA-actuated helical spring brake.

17. The SMA-actuated system of claim 16 wherein said SMA-actuated system is a window lifter mechanism and said payload is a window.

18. The SMA-actuated system of claim 17, further comprising a motor configured to rotate said rotatable member in said at least one direction.

19. The SMA-actuated system of claim 17, wherein a bias force generated by the weight of said window causes said rotatable member to rotate when said SMA-actuated helical spring brake is released.

20. The SMA-actuated system of claim 16 wherein said SMA-actuated system is a pin-latch mechanism for detaching two or members and further comprises:

a first member and a second member;

a latch affixed to said first member;

a pin pivotally coupled to said rotatable member, said pin being said payload and configured to engage said latch to join said first member to said second member; and

a bias device configured to maintain a bias force on said rotatable member,

wherein said SMA-actuated helical spring brake is configured to release said rotatable member so that said bias force can disengage said pin from said latch.

21. The SMA-actuated system of claim 20, wherein said rotatable member rotates when power is applied to sufficiently contract one or more SMA elements of said SMA-actuated helical spring brake.

22. The SMA-actuated system of claim 16 wherein said SMA-actuated system is a vehicle seat back release mechanism for permitting and inhibiting movement in relation to a seat bottom, said system further comprising:

a vehicle seat back rigidly coupled to an SMA-actuated helical spring brake and locked in an upright position;

a coupling rigidly coupled to said rotatable member; and

a safety lock configured to unlock said vehicle seat back in response to movement of said coupling,

wherein said coupling moves when said SMA-actuated helical spring brake is released.

23. The SMA-actuated system of claim 22 further comprising a trigger for actuating said SMA-actuated helical spring brake to unlock said safety lock, wherein said trigger is remotely located from and is in electrical communication with said SMA-actuated helical spring brake.

24. The SMA-actuated system of claim 22 wherein said SMA-actuated helical spring brake comprises:

a helical wrap spring arranged concentrically about said rotatable member and having a first spring end and a second spring end, said helical wrap spring including a number of turns that are biased radially inward and are configured to frictionally engage said rotatable member, said turns permitting rotation of said rotatable member in a first direction and inhibiting rotation of said rotatable member in a second direction; and

an anchor member having a first anchor point coupled to said second spring end and a second anchor point rigidly coupled to said vehicle seat back,

wherein, said SMA actuator is rigidly coupled to said vehicle seat back.

25. The SMA-actuated system of claim 22, further comprising an energy storage device that

stores energy when rotation of said rotatable member is inhibited, and

imparts a bias force onto said rotatable member for moving said coupling when rotation of said rotatable member is permitted.

26. The SMA-actuated system of claim 25, wherein said SMA-actuated helical spring brake and said vehicle seat back are configured to rotate about said rotatable member as said vehicle seat back moves from said upright position to a forward position, said SMA-actuated helical spring brake being configured to also frictionally engage said rotatable member as said vehicle seat back moves from said forward position to said upright position to rotate said rotatable member, thereby storing energy in said energy storage device.

27. A bender-actuated helical spring brake comprising:

a rotatable member;

a support configured to guide rotation of said rotatable member;

a helical wrap spring having a first spring end and a second spring end, said helical wrap spring including a number of turns that are biased radially inward and configured to frictionally engage said rotatable member, said turns permitting rotation of said rotatable member in a first direction and inhibiting rotation of said rotatable member in a second direction;

a support coupled to said second spring end; and

a bender actuator having a first end coupled to said first spring end and configured to deflect said first spring end to permit said rotatable member to rotate,

wherein said bender actuator generates a contraction force in a nonaxial direction to that of said bender actuator.

28. The bender-actuated helical spring brake of claim 27 wherein said bender actuator includes one or more of the following: a piezoelectric ceramic element, a bi-metal element and an SMA element.

29. The bender-actuated helical spring brake of claim 27 wherein the behavior of said bender actuator to actuate in said nonaxial direction compensates for manufacturing anomalies.

30. A method for actuating a shape memory alloy ("SMA") helical spring brake for imparting motion to a payload comprising:

powering an SMA actuator by applying electrical current to one or more SMA elements therein;

retracting an output drive member of said SMA actuator;

deflecting a spring end of a helical wrap spring to permit a rotatable member to rotate; and

moving said payload in response to said rotatable member rotating,

wherein said SMA actuator is powered for a predetermined duration of time to increase longevity of said SMA actuator.

31. The method of claim 30 wherein deflecting said spring end further comprises:

detecting that said output drive member is at an end-of-travel position; and

removing power from said SMA actuator.

32. The method of claim 30 wherein moving said payload further comprises:

detecting that said payload is at an end-of-travel position; and

removing power from said SMA actuator.

33. The method of claim 30 further comprising:

triggering activation of said SMA helical spring brake; and

electrically communicating said activation to power said SMA actuator.

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